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Real-Time Display of Ionospheric Electron Density Profiles from a Rocket-Borne Plasma Probe:
The Payload, Acquisition System, and the Real-Time Results

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This is the first in a series of reports dealing with the results of a major DNA program coordinating rocket, satellite, and ground-based equatorial studies at Kwajalein Atoll in the Marshall Islands. This report concentrates on the NRL contribution to the overall program, the direct measurement of the ionospheric plasma state as determined by on-board pulsed-plasma-probe (P^3_{LS}) observations of electron energies, densities, and density fluctuation power spectra. In particular, we describe our newly developed data acquisition system which acquired and displayed in real-time the ionospheric electron density profile as it was being measured by the P^3_M technique during the rocket flight.

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CONTENTS

REAL-TIME DISPLAY OF IONOSPHERIC ELECTRON DENSITY PROFILES FROM A ROCKET-BORNE PLASMA PROBE:

The Payload, Acquisition System, and the Real-Time Results

I. INTRODUCTION

On 23 August 1977, an ionospheric rocket payload was launched from Roi-Namur in the Kwajalein Atoll to study the cause-effect relationships between equatorial plasma instabilities, ionospheric irregularities, and scintillation phenomena.

The payload, illustrated in Figure 1, was instrumented with an ion mass spectrometer, two photometers (6300 Å and 5577 Å), electric field sensors, and a number of probes which utilized various techniques for the determination of electron density, temperature, and density fluctuation power spectra.

The launch, as part of a major DNA program carrying the code name EQUATORIAL WIDEBAND, was coordinated with Altair radar, top- and bottom-side soundings, and ground-based photometric measurements of F-region winds. These correlative observations permitted near-continuous monitoring of the ionospheric plasma state with emphasis on the development and morphology of regions of plasma irregularities.

The timing of the launch was critically hinged to space-time coincidence with the Wideband Satellite transit

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so that optimum correlation could be achieved between in-situ observations of ionospheric irregularities and scintillation spectra as measured by Wideband.

This report will focus on the NRL contribution to the overall program, the direct measurement of the ionospheric plasma state as determined by on-board pulsed-plasma-probe (P^3) observations of electron energies, densities, and density fluctuation power spectra. In particular we describe our newly developed data acquisition system which acquired and displayed in real-time the ionospheric electron density profile as it was being measured by the P^3 technique during the rocket flight.

The development of the real-time system was part of the NRL effort to expedite the transition from data collection to information transfer and publication. The capability was also developed for future programs involving ionospheric modification experiments, where in some cases the placement of upper atmospheric chemical releases can be too critical to rely on predicted trajectory information and ground-based ionosonde determinations of the F-layer peak. This subject is discussed in the closing section of this report. Before that we describe the P^3 experiment, the acquisition and display system, and the real-time results.

II. THE NRL PULSED PLASMA PROBE (P^3) EXPERIMENT

Since the P^3 technique has been described in detail elsewhere[1-4], only a brief account will be given here in order to facilitate an understanding of the data stream, acquisition system, and the relevance to geophysical units.

The pulsed plasma probe, shown in the payload sketch of Figure 1, carried the time-dependent voltage illustrated in Figure 2. A continuous chain of sawtooth sweeps was automatically applied to the probe and its guard electrode, with every 9th and 10th sawtooth replaced by a constant dc level V_B. The currents I_s sampled during the voltage pulses V_s on the sawtooth envelope were used to generate conventional current-voltage (I_s, V_s) characteristics from which absolute electron density and temperature are determined[5]. The interpulse sampling of currents ($\equiv I_B$) at the fixed baseline voltage V_B tracked ionospheric density variations which may have occurred during the sweep time τ_s, and provided the raw data for the determination of electron density fluctuation power spectra. The I_B values were sampled at a 512 and 1024 Hz rate during the pulsed sweep and fixed bias periods, respectively.

Nominal values for sweep voltage parameters (as defined in Fig. 2) were:

$$(V_-, V_+) = (-1.55\text{v}, +3.0\text{v})$$

$$V_B = +2.0 \text{ v}$$

$$\tau_s = 400 \text{ ms}$$

The electrometer response covered 5 full decades of current with a system of automatic switching which utilized 6 linear electrometer ranges. Twelve monitor levels uniquely identify the range of operation and the polarity of current collection. In this system every 0 to 5 volt telemetry value for the electrometer output [$TMV(I_s)$ or $TMV(I_B)$] had a range value (R_s or R_B) which determined the absolute magnitude and polarity of current collection through the linear relationship

$$I_{s,B} = a_n \cdot TMV(I_{s,B}) + b_n \qquad (1)$$
$$n = 1,..........12$$

With this system, "on scale" operation is always achieved for every I-V characteristic, regardless of the ionospheric plasma state.

III. THE ACQUISITION AND DISPLAY SYSTEM

The specific tasks accomplished by the NRL real-time data acquisition system were:

i) The acquisition and storage on disk file via the PDP 11/10 digital computer all data relevant to the NRL Pulsed Plasma Probe (P^3) in the PCM Telemetry Stream (i.e., I_B, I_s, V_s, R_B, R_s and magnetometer response), and

ii) The reduction and display in real-time of the relative electron density profile (indicated by

baseline current measurements I_B) as a function of time and predicted altitude.

We describe below in general terms the programming effort involved and discuss some of the more important details in a real-time acquisition system.

The general method employed in the data acquisition and display, is illustrated in the flowcharts of Figs. 3-5. There are two Interrupt Service Routines (ISR's) and one main Fortran routine. The sequence is driven by interrupts to the PDP 11/10 Digital Data Interface Unit (DR11-K) control lines. The interrupts, which occur at the beginning of pre-selected words, were supplied by a CONIC decommutator unit (DPAD). The unit is programmable and facilitates interrupt position changes throughout the full 32 word range of a subframe*.

A. Raw Data Description

Words 4, 6, 26, and 27 in the PCM format shown in Fig. 6 were relevant to the P^3 experiment. Below we describe the significance of each of the main frame words.

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* <u>NOTE</u>: One mainframe consisted of 16 minor-frames (or sub-frames) each of 32 words (0-31) in length. The data rate of the PCM stream was 1024 subframes/sec = 64 mainframes/sec = 64 x 16 x 32 (32.768×10^3) words/sec. Fig. illustrates one mainframe and the position of relevant NRL P^3 data within that frame.

P^3 baseline current I_B and sweep current I_s appeared alternately in word 26 of each subframe (i.e., they were subcommutated at a 512 Hz rate). The associated range monitors, R_B and R_s, followed immediately in word 27. In addition, in every 8th occurrence of word 27, the I_B range monitor value was replaced by the applied probe voltage sweep monitor V_s.

Word 6 in subframes 3, 7, and 11 of each mainframe provided a ground reference, a +5 volt reference, and magnetometer data, respectively. The frequency of magnetometer data sampling was therefore once per mainframe (= 16 subframes) or 64 Hz.

Word 4 in subframe 1 of each mainframe was used as a synchronization indicator for the TM signal and served as a flag marking lift-off.

B. Interrupt Service Routines

DRROU sorted data, and set up and filled three data buffers using a double buffering scheme. Each data type (i.e., I_B, I_s,...) was uniquely tagged for later reference by the reduction software. The three buffers handled by this routine were those containing: (1) I_B, I_s, V_{SWEEP}, (2) I_B (for display only), and (3) magnetometer, ground and 5 volt reference.

DRROU performed no Input or Output operation but set flags for either ARROU or the main FORTRAN routine to test

for transfer to disk or display. A buffer was full when the word count reached 512.

ARROU kept time (the real-time clock was programmed to interrupt on overflow every millisec), transferred full data buffers to disk, and tested flags set by DRROU to determine whether the I_B, I_s, or magnetometer buffers were full.

C. Main FORTRAN Routine (IBDIS3)

IBDIS3 provided for initialization and plotting routine set-up, as well as the I_B calculation from Eq. (1). The I_B values were then averaged over 1.5 sec intervals for display on a Tektronix video controller.

IV. REAL-TIME RESULTS

In the application reported here, consecutive 1.5 sec time elements were blocked in real-time and the averaged value of I_B plotted as a measure for relative electron density variations. Averaging conserved program running time and smoothed payload spin modulation of collected currents. A replay of the real-time results is presented in Figure 7 with the bottom abscissa showing time after lift-off and the upper abscissa showing the actual altitude.

Detailed post-flight determinations of electron density through standard analysis of the I_S-V_S characteristics proved the real-time $\langle I_B \rangle$ profile to be an excellent monitor of relative electron density, the proportionality being $\langle I_B \rangle = 10^{-6}$ A $- N_e \approx 3\ (10^4)\,cm^{-3}$. Reference 6 discusses some limitations on the assumption $I_B \propto N_e$.

We note that the payload had a predicted apogee of 850 km but only reached an altitude of 160 km as a result of a failure in second stage separation. The fact that the payload never got to the F-layer was evident in the real-time relative density profiles that did not show the level of currents expected for F-region penetration.

V. COMMENTS AND CONCLUSIONS

We have described our recently developed real-time data acquisition and display system with emphasis in its first application in a rocket program funded by the Defense Nuclear Agency.

In real-time the system acquired the PCM elements of a rocket borne pulse plasma probe and plotted the relative electron density profile as it was being measured during the flight.

An unfortunate failure in the vehicle's second stage separation served to demonstrate one of the important features of the real-time system particularly as it can be applied to future programs involving chemical releases at ionospheric altitudes. The vehicle was to deliver the payload to the top-side of the F-region but only achieved a 160 km apogee...a result which was evident in the real-time density profile. Had an F-region chemical release been an objective, the mission would have failed. However, future programs with the capability for real-time in-situ profile determination at the position of the explosive payload could easily pinpoint primary target areas (such as the bottom-side gradient of the F-layer or the F-layer peak) as well as secondary targets (like sporadic-E). In the vehicle failure described here, easily considered catastrophic if an F-region release was intended, a secondary success could have been achieved by retiming the release for the downleg penetration of the E-region irregularities shown in Fig. 7.

<u>Some Software considerations</u>. There were two areas which required special attention in the real-time data acquisition and display routines. Briefly, they were in the areas of:

i) Synchronization loss (or, signal/interrupt loss) and,

ii) Loop timing.

These two elements were not independent in that the additional software necessary to account for signal losses exceeded the allowed loop time of the ISR DRROU.

Since I_B and I_S occurred alternately in word 26, the acquisition routines had to track and identify each subframe as it was sampled. It was necessary to detect a loss or distortion of this information so that program logical flows were not corrupted. We note that in addition to the interrupt an even or odd subframe indicator would be desirable. This was not originally available but was finally implemented by synchronization through interrupt counting.

The final real-time display routine was run independently of the permanent data acquisition software Storage to the PDP/11 disk medium was accomplished immediately after the flight by replaying the flight PCM stream from the flight tape at one-half the actual data rate (16.38 F/sec). Half speed playback was necessitated by the increased loop time resulting from synchronization problems. In the future this dual procedure will not be necessary since a simpler method of re-establishing sync will be implemented through hardware. Following playback and within one hour after flight termination, detailed data analysis routines (N_e), δN_e, and T_e) were initiated. These results will be the subject of a follow-up report.

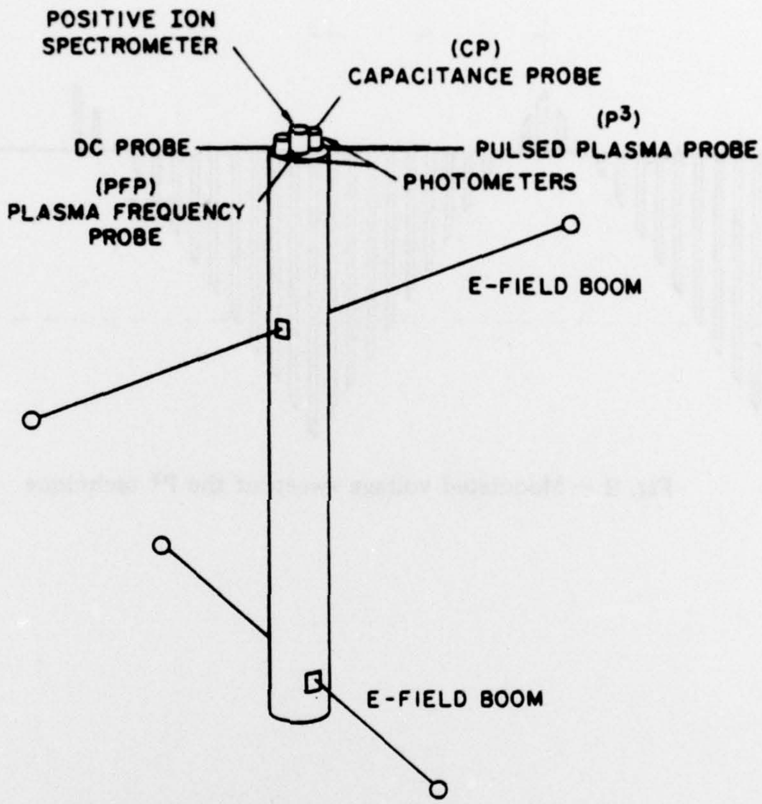

Fig. 1 — DNA equatorial wideband rocket payload

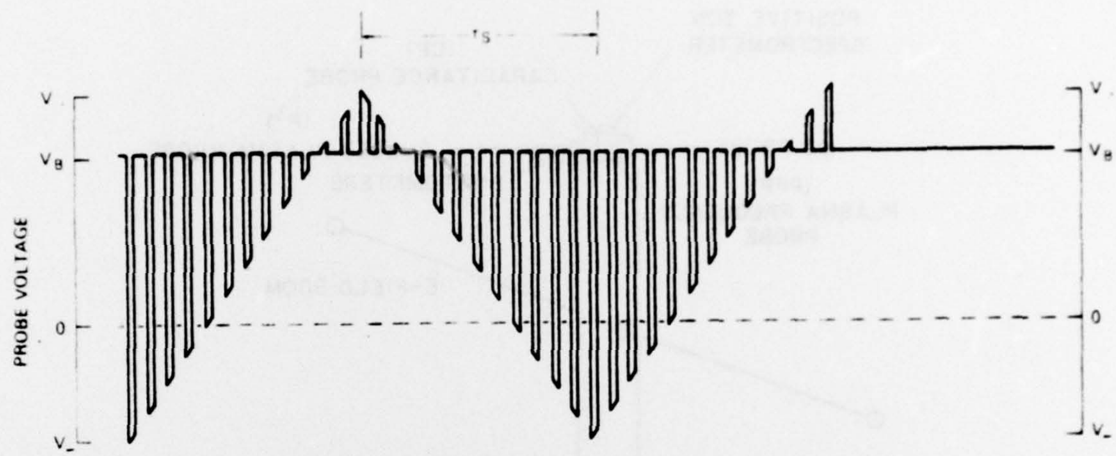

Fig. 2 — Modulated voltage sweep of the P^3 technique

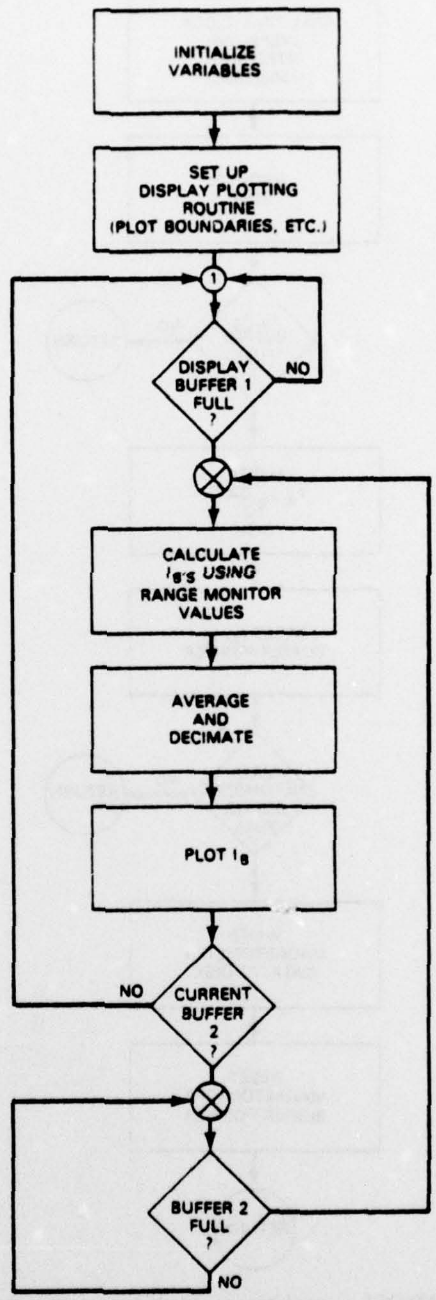

Fig. 3 — IBDIS3 — main Fortran routine

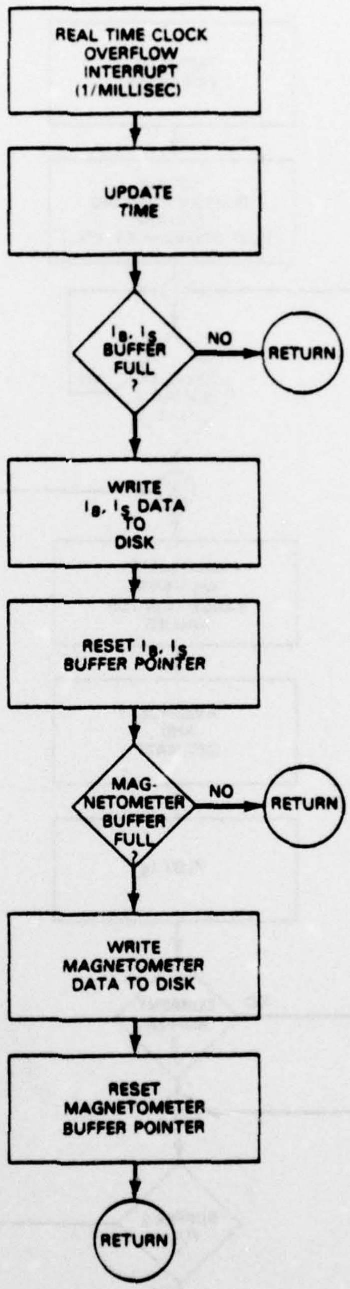

Fig. 4 — ARROU — real time clock interrupt service routine

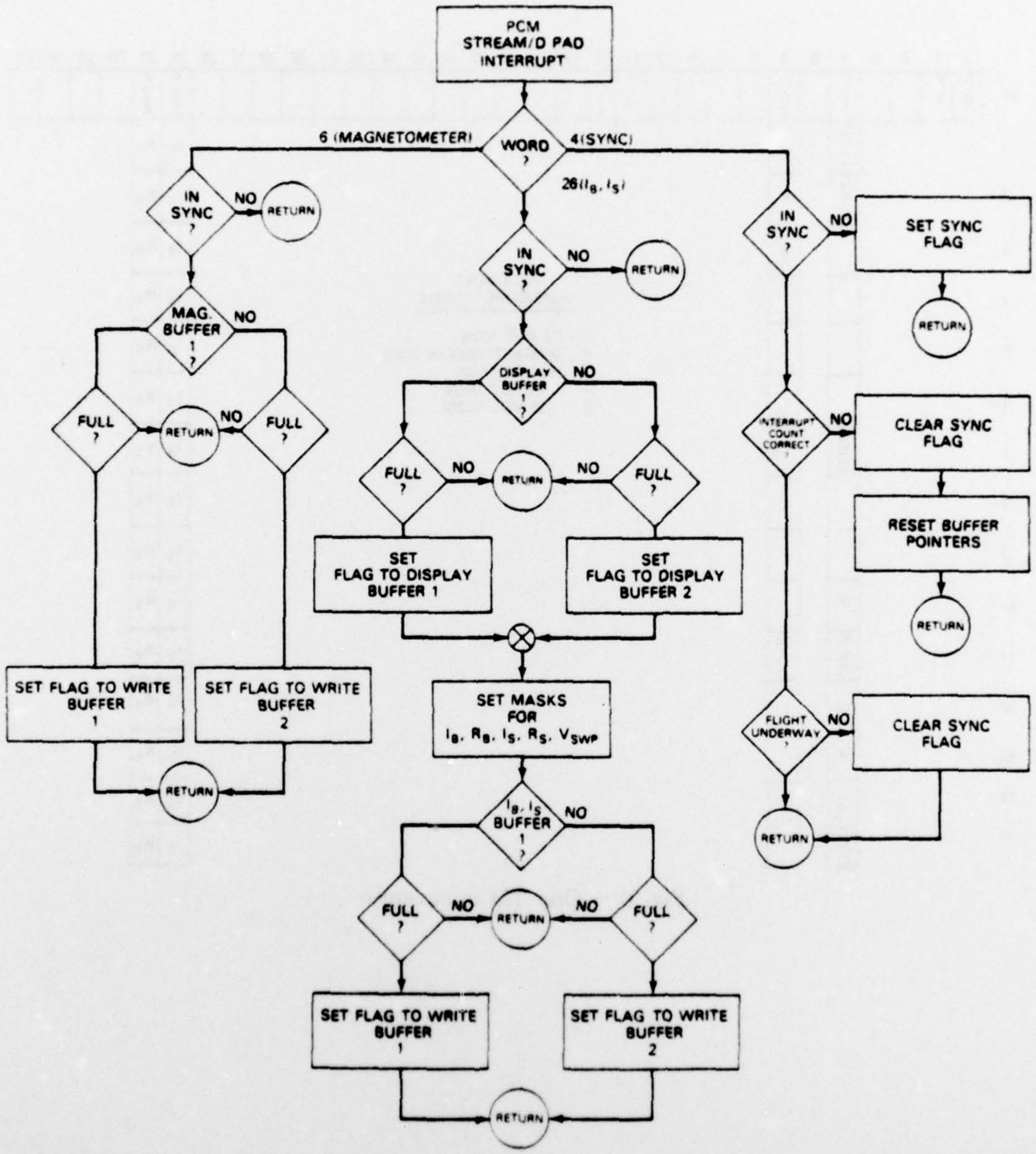

Fig. 5 — DRROU — DPAD interrupt service routine

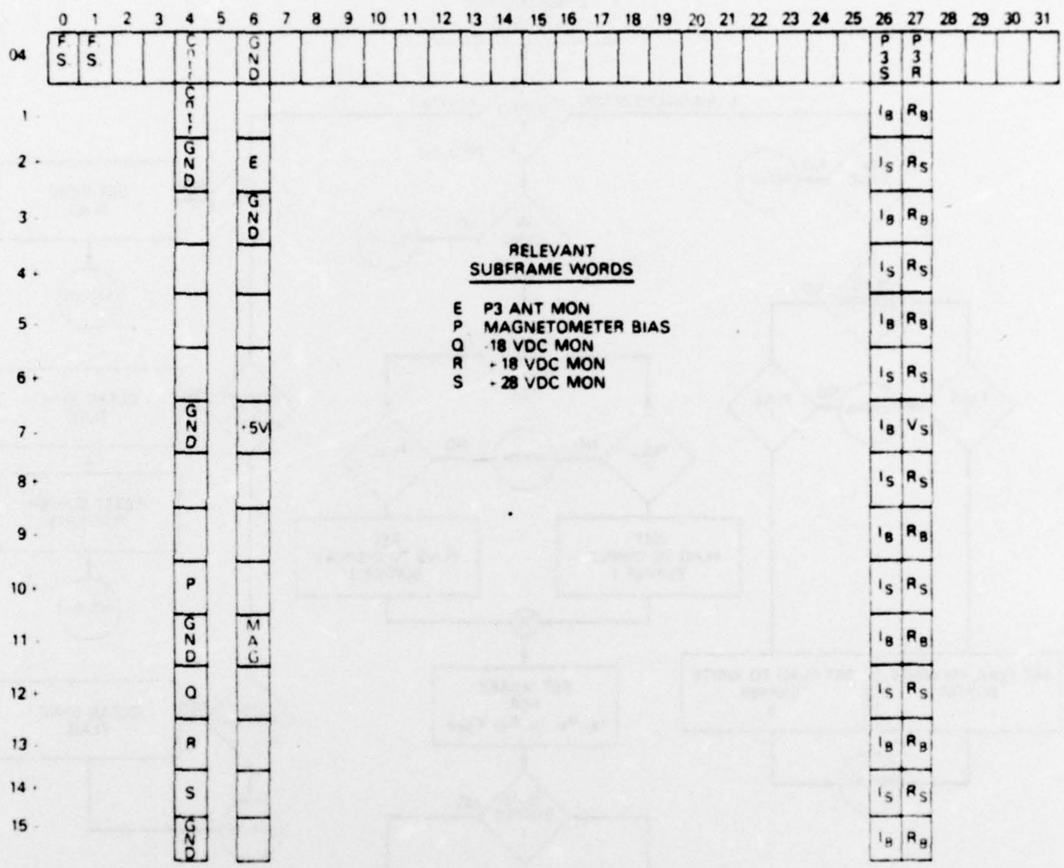

Fig. 6 — One TM mainframe

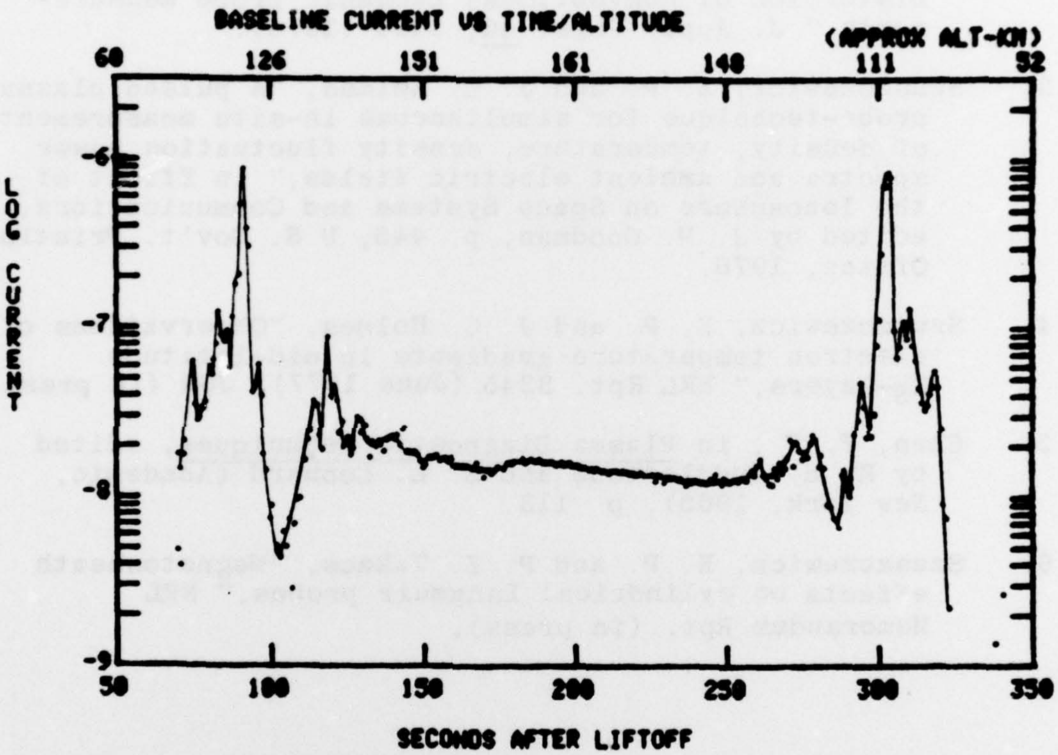

Fig. 7 — Real-time results — I_B vs time and altitude

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